

3) Mechanical Sensors

**PROGRESS TOWARD A BULK MICROMACHINED TUNNELING TIP  
MICROACCELEROMETER**

*Frank T. Hartley and Ben Dolgen*

*Jet Propulsion Laboratory  
4800 Oak Grove Drive  
Pasadena, CA 09119  
Tel 818-354-3139*

*Paul M. Zavracky*

*Northeastern University  
360 Huntington Avenue  
Boston, MA 02115  
Tel 617 -272-2919  
Fax 617-373-8970*

**Abstract**

Ultrasensitive accelerometers are needed for microgravity measurement of orbital drag and active isolation systems. We have designed an accelerometer capable of measuring accelerations of the order of  $10^{-8}$  g. A tunneling tip sensor can be used as a position sensor with a potential performance advantage of two orders of magnitude over capacitive sensors. In this paper, we disclose our progress in the fabrication and measurement of a bulk microaccelerometer which employs a tunneling tip. Fully assembled accelerometers consisting of four separate die have been fabricated. The device employs a unique folded spring system with a low spring constant. To protect the tunneling tip, we have employed electrostatic clamping. Stiction has not been observed, but the required clamping voltage is greater than expected. We have developed a simple model to analyze our results.

**Background**

Early work on tunneling sensors has been performed by Kaiser, et al<sup>i</sup>. They have demonstrated the capabilities of a tunneling tip sensor for use in position measurements. Analysis of noise has been presented. Tunneling tips have been applied to accelerometers and bolometers<sup>ii</sup>. The issue of tunneling tip protection was approached by using a two cantilever system. While this architecture may provide protection, the scheme requires additional elements to implement and the resonance and positioning of two separate cantilevers must be considered.

We have approached the problem with an eye toward protecting the tip only when needed<sup>iii</sup>. To accomplish this we use the structure shown in figure 1. The cross-section shows an accelerometer that is constructed from four die. The two die in the center are identical but inverted to form a proof mass and spring system. The 0.2 gm proof mass is supported by a weak spring system with a spring constant of approximately 2 newtons/meter. The proof mass is one square centimeter in area. Two other die complete the structure. The upper die in the figure contains a tunneling tip, and four quadrature electrostatic field plates. The tip itself is anisotropically etched in silicon and is designed to be flush with the surface of the wafer. The lower die contains a single electrode covered with a Low Temperature Oxide (LTO) layer. It is used both for controlling and maintaining the position of the proof mass and for electrostatically clamping the proof mass while not in use. To create a surface indexed bond, channel are anisotropically etched in both the tip and force plate die and bond metal is placed in these locations only.

The electrostatic force is proportional to the square of the voltage and the inverse square of the electrode spacing. The cavity between the proof mass and the force plate is designed to about five microns and was set by the requirements of the force feedback electronics used to constrain the proof mass in its neutral

position while operating. Interconnection of the electrodes from one die to another is accomplished during the eutectic bonding operation. This allows access of all bond pads from one side of the assembled structure.

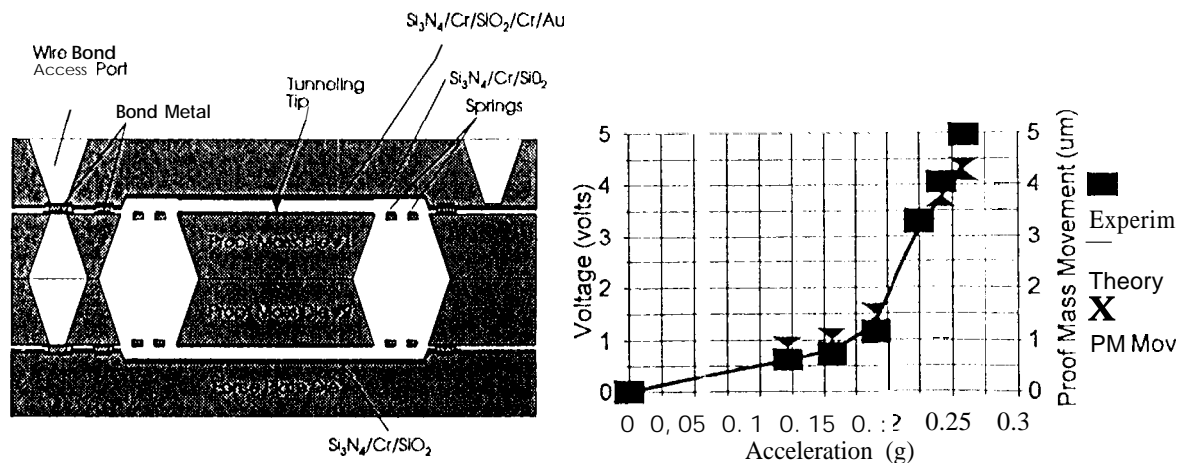
In operation, there is no contact between the force plate and the proof mass. The application of an electrostatic field between the proof mass and the force plate will accelerate the proof mass toward the force plate. However, during transit periods, an electrostatic field is applied to the proof mass. A silicon dioxide layer above the metallic force plate maintains a one half micron spacing between it and the proof mass. With a DC voltage of only a few volts, a theoretical force equivalent to several hundred g's can be obtained. This force is sufficient to clamp the proof mass immobile during handling, shipping and lift-off.

Measurements of a clamped proof mass have shown that the full theoretical force is not achieved. This has been attributed either to low frequency surface undulations common in chemomechanically polished wafers or imperfections in the LTO insulating layer. Measurements of wafers surfaces reveal that a surface height undulation of as much as one micron over a centimeter is common. To overcome this problem, wafers must be carefully specified to the vendor.

Preliminary measurements of the accelerometer in a capacitance sensing mode have been conducted (Figure 2). The accelerometer is placed on end. By tilting the accelerometer, the effective acceleration of the proof-mass can be varied. A simple control circuit employing DC force feedback was used. In Figure 2, the required voltage to maintain the proof mass in its neutral position is plotted as a function of acceleration.

## Conclusion

New methods of producing surface indexed bonds and protecting a tunneling tip have been disclosed. Measurements indicated that a force plate separated from the proof mass by a one half micron of silicon dioxide can be effective in clamping the proof mass against accelerations as high as a few hundred g's with only a few volts applied. In addition, the advantages of using an AC applied field in a force feedback system are presented,



<sup>i</sup> S.B. Waltman and W. J. Kaiser, "An Electron Tunneling Sensor," Sensors and Actuators, Vol. 19, pp 201-210, (1989).

<sup>ii</sup> T.W. Kenny, W.J. Kaiser, H.K. Rockstad, J.K. Reynolds, J.A. Podosek, and E.C. Vote, "Wide Bandwidth electromechanical Actuators for Tunneling Displacement Transducers," JMEMS, Vol. 3, No. 3, pp 97-104, (1994).

<sup>iii</sup> P.M. Zavracky, F. Hartley, N. Sherman, T. Hansen and K. Warner, "A New Force Balanced Accelerometer using a Tunneling Tip Position Sensor," The 7th International Conference on Solid-State Sensors and Actuators, Yokohama, Japan, June 7-10, 1993.